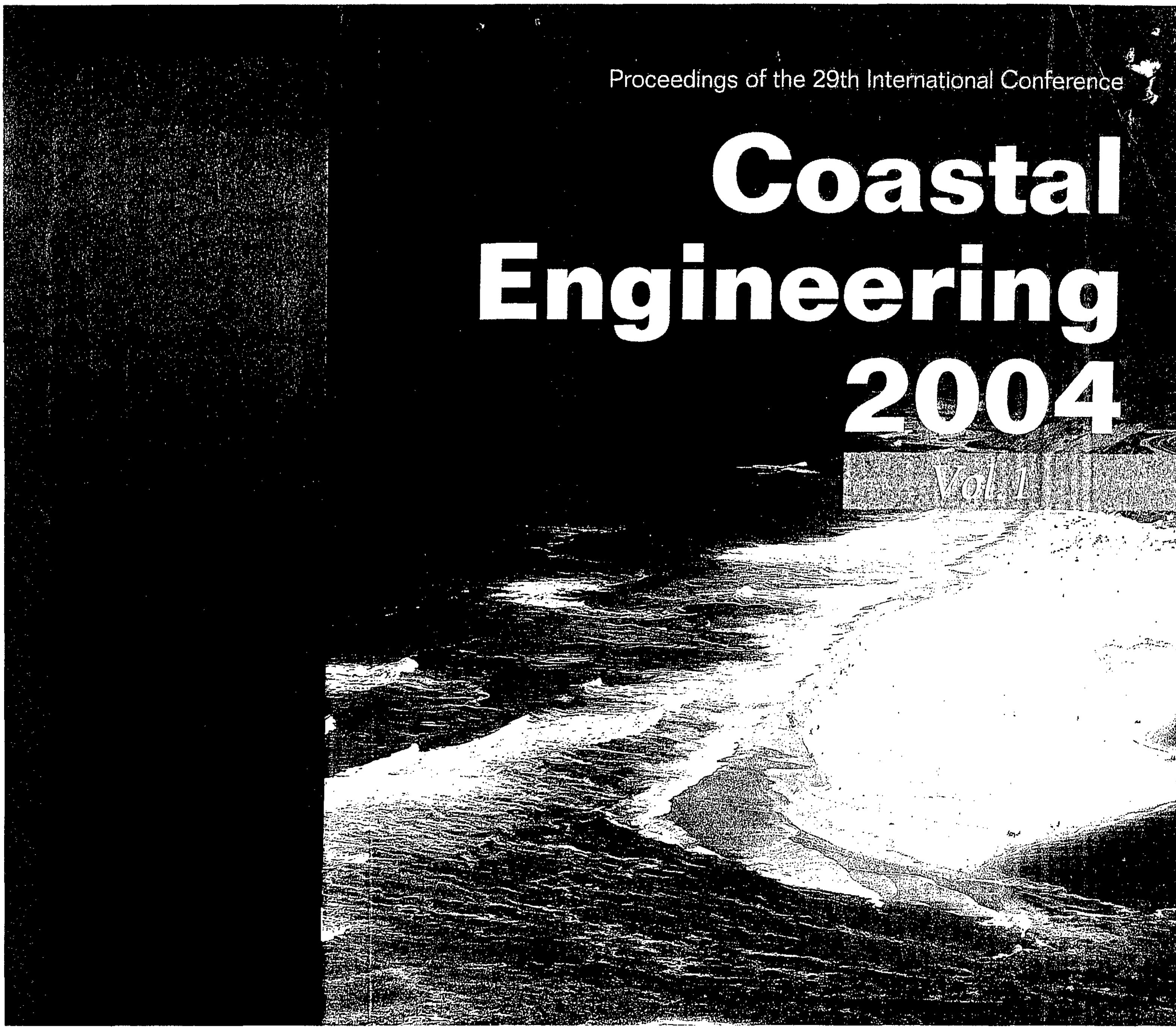
Proceedings of the 29th International Conference
Coastal
Engineering
2004
Vol. 1

16. J. T. Kirby and J. M. Kaihatu, *Proc. 25th Intl. Conf. Coast. Engrg.*, 1144 (1996).
17. J. Veeramony and I. A. Svendsen, *Coast. Engrg.* **39**, 93 (2000).
18. Y. Chen, R. T. Guza, and S. Elgar, *J. Geophys. Res.* **102**, 25035 (1997).
19. R. E. Scraton, *Comp. Jour.* **7**, 246 (1964).
20. S. Hasselmann and K. Hasselmann, *J. Phys. Oc.* **15**, 1369 (1985).
21. E. B. Thornton, *J. Phys. Oc.* **7**, 137 (1977).
22. V. Zakharov, *Eur. J. Mech. B/Fluids* **18**, 327 (1999).
23. J. M. Smith and C. L. Vincent, *J. Geophys. Res.* **108**, 3366 (2003).
24. Y. Toba, *J. Oc. Soc. Jpn.* **29**, 209 (1973).
25. J. M. Kaihatu and J. T. Kirby, *Phys. Fluids* **7**, 1903 (1995).
26. J. M. Kaihatu, *J. Wtrway., Port, Coast. and Oc. Engrg.* **127**, 113 (2001).
27. T. H. C. Herbers, N. R. Russnogle, and S. Elgar, *J. Phys. Oc.* **30**, 2723 (2000).

MESOSCALE WAVE ENERGY DISSIPATION OVER HETEROGENEOUS SEDIMENTS

PAUL A. WORK
HÜSEYİN DEMİR

School of Civil and Environmental Engineering, Georgia Tech – Savannah
210 Technology Circle, Savannah, Georgia, 31407 USA

JAMES M. KAIHATU

Oceanography Dynamics and Prediction Branch, Oceanography Division (Code 7322),
Naval Research Laboratory, Stennis Space Center, MS 39529-5004 USA

GEORGE VOULGARIS

Marine Science Program, Dept. of Geological Sciences, Univ. of South Carolina,
Columbia, SC 29208 USA

Measurements describing the evolution of wave energy spectra as waves propagate across a large shoal are described. The shoal is shore oblique, 2 km by 10 km in extent, with relief of up to three meters over bathymetry with ambient depth 10-12 m. The region is sediment starved, and bottom roughness displays spatial variability due to rock outcrops. Field measurements intended to investigate the effects of this shoal on waves, currents, and sediment transport in its lee reveal strong cross-shore gradients in energy density and energy flux, well outside of the surf zone, in conditions of minimal wind, which are attributed to bottom friction. The dissipation displays the expected frequency dependence, in that it decreases in significance as wave frequency increases, but this trend is not as strong as available theoretical predictions would suggest.

1. Introduction

The potential significance of wind wave energy losses induced by bottom friction on the shoreface, outside of the surf zone, has long been recognized (Putnam and Johnson 1949, Bretschneider and Reid 1954). These losses have also been documented in the field (e.g. Herbers et al. 2000, Ardhuin et al. 2004). Neglect of these losses leads to overestimation of nearshore sediment transport rates and over-design of nearshore coastal structures, among other problems.

The magnitude of energy losses due to interactions between surface gravity waves and the seafloor depends on bed characteristics and sediments. Most bedforms are not resolved by numerical models of wave transformation, but may be accounted for by appropriate choice of roughness coefficients in an empirical description of losses due to bottom friction. Even in the absence of significant

bedforms, the morphology, texture, and porosity of the seafloor could strongly influence energy losses.

Recent field measurements are considered that define mesoscale (1-10 km) changes in wave energy spectra. The site (Long Bay, South Carolina USA) includes a heterogeneous patchwork of sand, shell, and rock outcrops at depths of 0-12 m and features a large shoal. Data defining spatial variations in seafloor characteristics are available from a combination of sidescan sonar, video, backscatter, and seismic measurements. Measurements of directional wave energy spectra are used to quantify wave energy dissipation, and these measurements are compared to available predictive theories.

2. Site and Geophysical Information

The site considered is located in Long Bay, along the "Grand Strand" of South Carolina (Figure 1). The shoreline in the region considered is nearly linear, with no tidal inlets of any significance, and faces southeast.

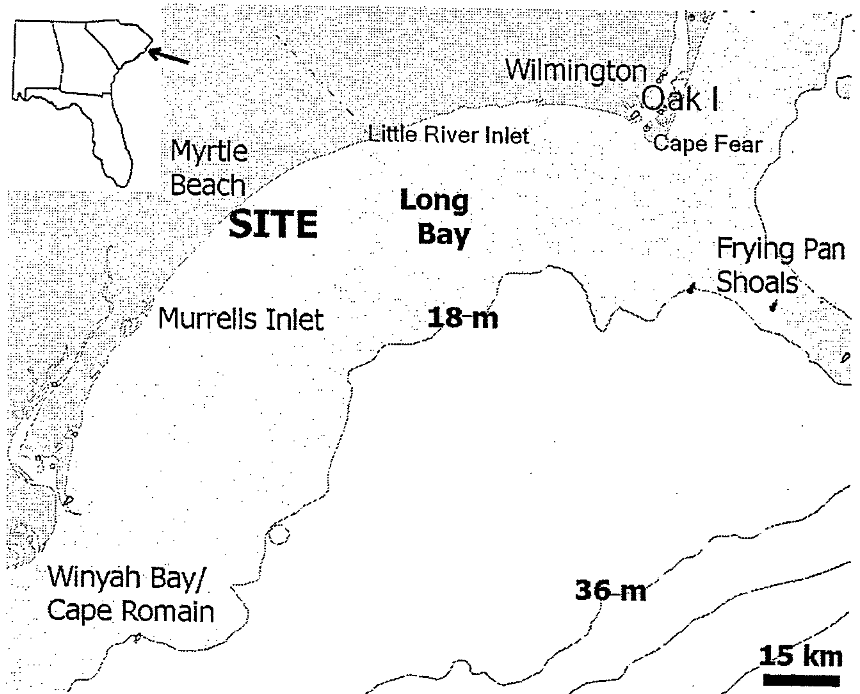

Figure 1. Site location.

The site was chosen for investigation because it features a large (2 km x 10 km x up to 3 m relief), persistent shoal that would be expected to play a controlling role in the local wave, current, and sediment transport patterns. Figure 2 shows the configuration of the shoal in 1933. The present day configuration is very similar.

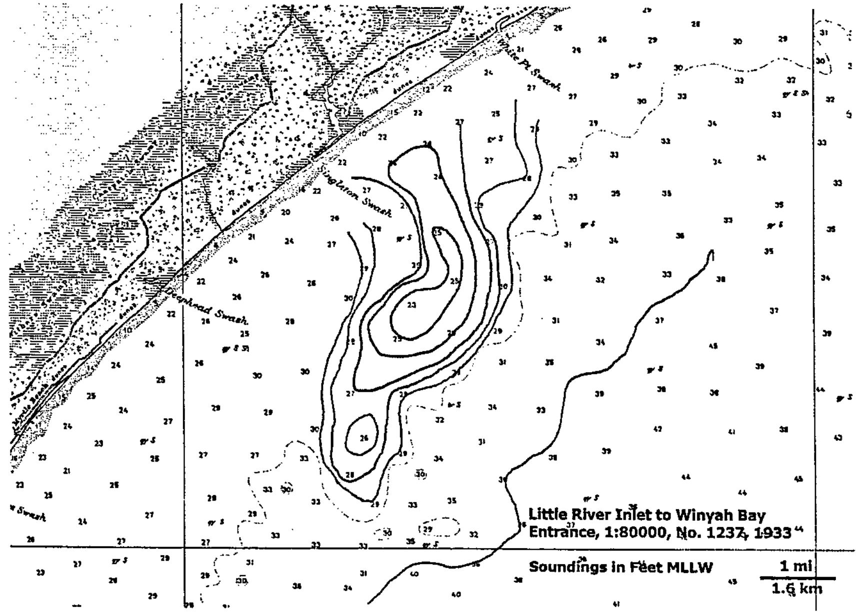

Figure 2. Detail of 1933 nautical chart, showing shoal offshore of Singleton Swash.

Previous investigators collected a large amount of geophysical information that was used to develop high resolution bathymetry for the region, as well as estimated sediment thicknesses (Figure 3; Baldwin et al. 2004. Ojeda et al. 2004). The region was interpreted as being sediment starved, with significant accumulations of sediment only within the ebb tidal deltas up- and downcoast of the area considered, close to the surf zone, and within the shoal that is the focus of the measurements described here. Rock outcrops are prevalent throughout the region, and rock underlies the sediment deposits.

Several research and engineering questions were posed for the site:

1. What is the long-term influence of the shoal on waves, currents, and shoreline change?
2. How significant is the wave energy dissipation as waves pass over the shoal? What controls the dissipation?
3. Does the observed dissipation show the expected dependence on wave frequency?
4. Can the observations be reproduced with existing models of wave transformation?
5. How important is it to resolve spatial variations in bottom roughness, porosity, and sediment thickness?

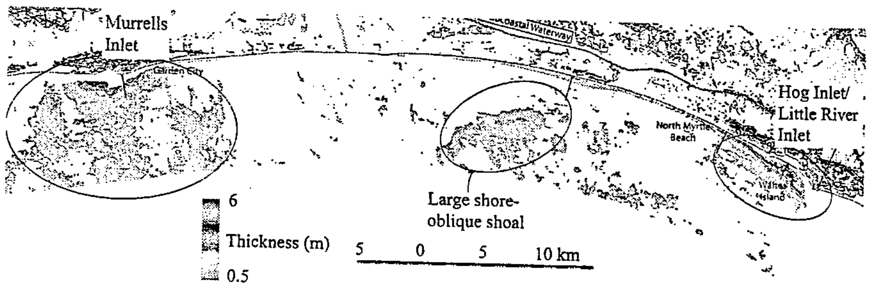

Figure 3. Sediment thicknesses as estimated from geophysical surveys. Adapted from Baldwin et al. (2004). White regions feature less than 0.5 m sediment thickness.

3. Field Measurements of Directional Waves and Currents

Instruments were deployed in 2001-2002 to provide the first dataset to address the questions posed above. Four acoustic sensors were deployed along a shore-normal transect crossing the top of the shoal, for measurement of mean flows and directional wave energy spectra (Figure 4). The mean flows will not be addressed here; sensitivity tests using the SWAN wave transformation model (Booij et al. 1999) suggested that the measured mean flows rarely played a significant role in wave transformation, given their typical magnitudes and direction. The focus will instead be on measured and modeled wave energy spectra.

The four instruments were all deployed in up-looking mode on the seafloor. Table 1 provides information on each station and sensor. The station closest to shore, station 4, provided only coarse (along the frequency axis) non-directional wave spectra so will not be considered further. Although all sensors measured velocity acoustically, based on measured Doppler shift, computation of wave spectra differed slightly between instruments. Directional wave energy spectra from the RD Instruments equipment are derived from velocities measured at multiple locations near the top of the water column, where attenuation is less significant. The Nortek instrument uses the P-U-V technique, which involves processing of three time series (pressure + two orthogonal, horizontal components of instantaneous velocity) near the sensor head (i.e. near the seafloor). The signal to noise ratio for this latter approach is better for low frequency wave energy than for high frequency energy.

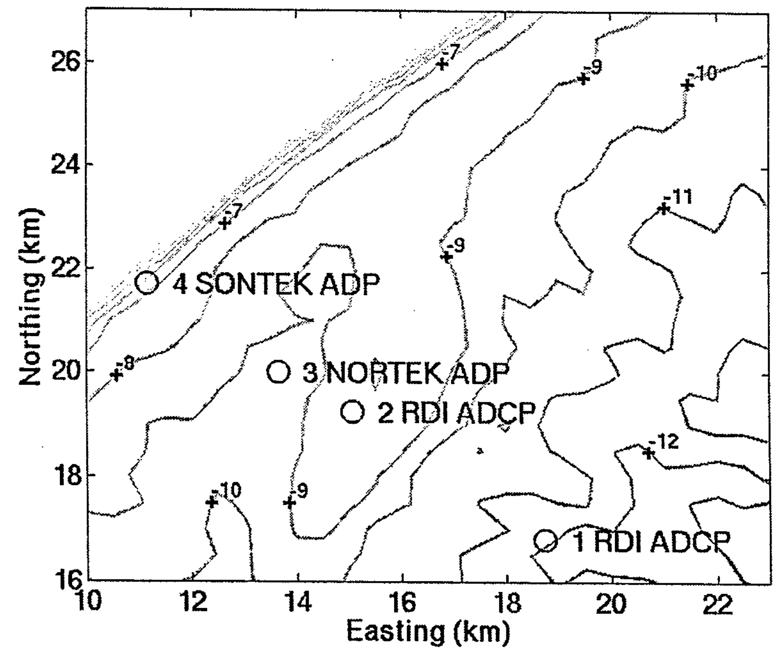

Figure 4. Locations of instruments deployed during 2001-2002 campaign. Depth contours are provided at 1 m contour interval.

Table 1. Deployed instrumentation for measurement of directional wave energy spectra and mean flows. All instruments recorded mean flow at 15-min intervals and wave energy spectra at 1.5 hr intervals. See Figure 4 for station locations.

Station	Instrument	Wave energy spectra	Mean depth (m)	Deployment period
1	600 kHz RD Instruments ADCP	Directional	11.8	11/09/01-12/18/01
2	1.2 MHz RD Instruments ADCP	Directional	8.1	11/09/01-12/23/01
3	2.0 MHz Nortek Aquadopp	Directional	9.4	11/09/01-1/17/02
4	1.5 MHz Sontek Argonaut-XR	Non-directional	6.7	11/09/01-5/01/02

4. Evolution of Wave Energy Spectra

In general, the measured waves at the site may be affected by refraction, diffraction, shoaling, wind, mean flows, bottom friction, wave-wave interactions, whitecapping, and breaking. Some of these processes or factors may be eliminated from consideration, particularly through judicious choice of

measurements for comparison. A two-day period within the measurement record was found during which winds were negligible (<5 m/s mean wind speed) and waves were close to 1 m in height and within 30 degrees of shore normal. This interval will serve as the focus of the remainder of this paper. By focusing on these measurements, wind inputs and whitecapping are eliminated from consideration, and wind-induced flows, which might contribute to refraction, are minimal. With wave height to water depth ratios of 1:10 for this two-day period, depth-induced breaking will not occur at any of the three stations considered here.

Note also that with a typical wave phase speed of 8 m/s (for a wave period of 6 seconds and water depth of 10 m), approximately 12 minutes are required for waves to travel the 6 km from Station 1 offshore to Station 3 in the lee of the shoal. This is comparable to the duration of the data bursts from which wave spectra are estimated. Thus it is assumed that the propagation time can be neglected when comparing waves measured at one station to those measured at another.

Figure 5 shows non-directional wave energy spectra measured simultaneously at the three stations at one instant. This result is fairly typical of the entire two-day period. The peak of the spectrum shows a significant drop in energy as the waves pass over the shoal, and most other frequencies less than 0.25 Hz see a less marked decrease.

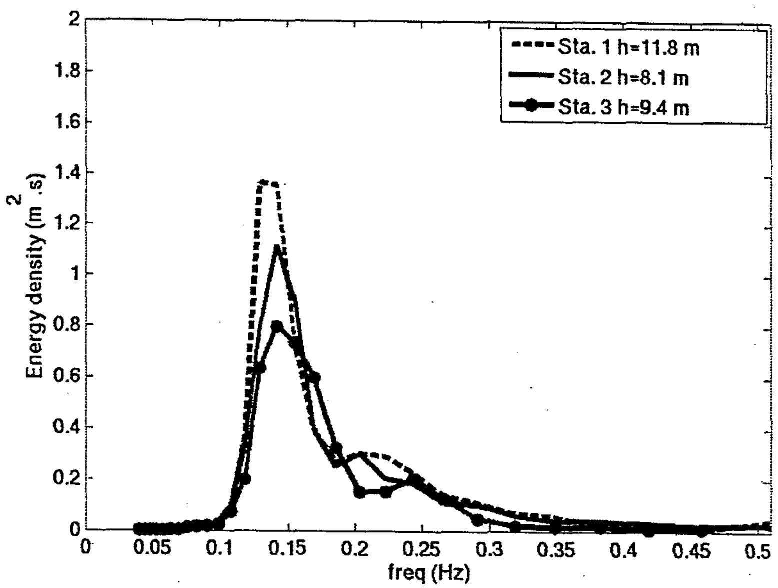

Figure 5. Measured energy spectra at 12:30GMT 24 November 2001.

Some of the changes apparent in Figure 5 could be due to refraction and shoaling. Refraction and shoaling could also mask energy dissipation to some degree: shoaling will tend to increase wave energy density at the same time that bottom friction reduces it. An integrated wave energy flux was computed to try to remove shoaling effects; this will simply be referred to as energy flux hereafter. The energy flux is defined as:

$$F = \frac{1}{f_{cut}} \sum_{i=1}^{I} E_i Cg_i \Delta f_i \qquad (1)$$

where E_i denotes the wave energy density for the ith frequency bin, Cg_i is the corresponding group velocity, Δf_i is the width of the ith frequency bin, and f_{cut} is the range of the I frequencies over which the numerical integration is performed. Per linear wave theory, this quantity is conserved for the case of waves propagating towards bathymetry that does not have any longshore variation or longshore variability in mean flows. Thus it facilitates separation of shoaling and refraction effects within the measurements.

The measured spectra were divided into three frequency bins: low (0-0.15 Hz), medium (0.15-0.25 Hz) and high (0.25-0.35 Hz). For each record, the ratio of local energy flux to incident energy flux (i.e. at the offshore station) was computed. Mean values of these quantities, averaged over the two-day period, are shown in Figure 6.

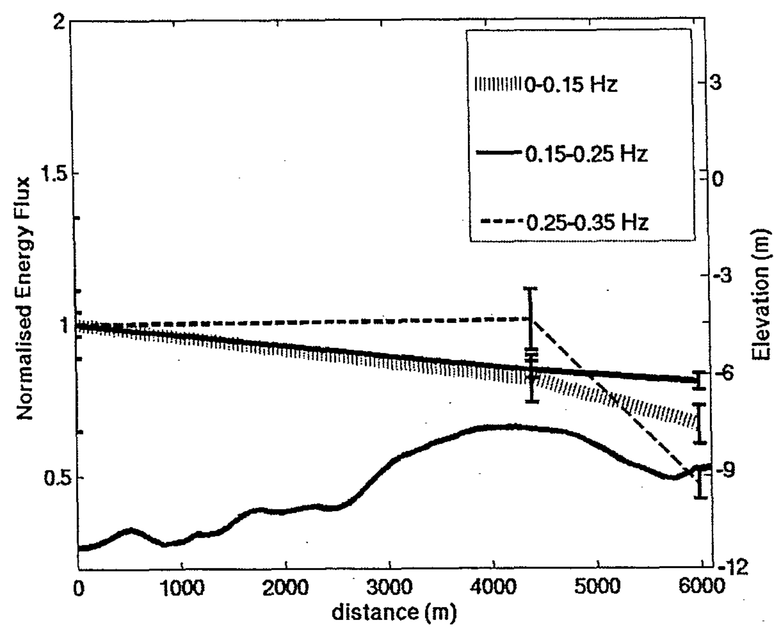

Figure 6. Mean values (N = 33) of the ratio of local wave energy flux to incident energy flux for three different frequency bands. Bathymetry shown by bottom curve. Error bars explained in text.

The RD Instruments packages compute non-directional spectra from three independent time series: pressure, velocity, and surface track. Discrepancies between energy fluxes derived via the three different approaches were assumed to be indicative of experimental error at a given location and time. The error bars shown in Figure 6 indicate the maximum of these estimated errors for each location. The errors are much larger for the high frequency band, as expected because of the more severe signal attenuation. Attention will be devoted instead to the two lower frequency bands.

It is evident in Figure 6 that:

1. Energy dissipation between the offshore station and the shoal are similar for both the low- and medium-frequency bands.
2. The low-frequency band displays relatively more energy dissipation, on average, than the medium-frequency band for the shallower region in the lee of the shoal.

Note that shoal-induced refraction effects in the lee of the shoal would be expected to increase energy flux more for the low-frequency band. So the differences between the two curves in the lee of the shoal would be expected to be more pronounced if refraction effects could be removed.

5. Wave Model Predictions

As no analytical solutions are available to describe all of the wave transformation processes at the site, a numerical wave model must be used to further isolate wave transformation processes. The SWAN wave transformation model (Booij et al. 1999), which describes the propagation of directional wave energy spectra over arbitrary bathymetry, accounting for refraction and shoaling due to spatial gradients in bathymetry and currents, wind wave generation, wave-wave energy transfers, and dissipation due to bottom friction, whitecapping, and breaking, was applied. This allowed certain mechanisms, such as bottom friction, to be turned on and off to isolate processes.

Whitecapping and depth- or wave steepness-induced breaking have both already been eliminated, but several other energy dissipation mechanisms remain as possibilities:

1. dissipation within the bottom boundary layer, whether or not significant bedforms exist.
2. dissipation via flows through pores in the sediment.
3. energy and momentum transfer to the seabed.

Of these, only the first was concluded to be significant. The third can be important for many cohesive sediments, but is much less significant for the noncohesive sediments and rock found at the site considered here. The second process was eliminated based on estimates of power dissipation via porewater flow, as described by the linear model discussed in Dean and Dalrymple (1991).

Simulations with SWAN were performed to investigate the suitability of existing descriptions of bottom friction for this scenario. Figure 7 shows the results for the low-frequency band. The top line shows the SWAN model result in the absence of bottom friction, and reveals an increase in energy flux in the lee of the shoal that is attributed to shoal-induced refraction. This is also evident in the instantaneous measurements (crosses). The model, when using the Madsen et al. (1988) friction model with the "standard" roughness coefficient of 0.05, underestimates the dissipation for this instance (open circles).

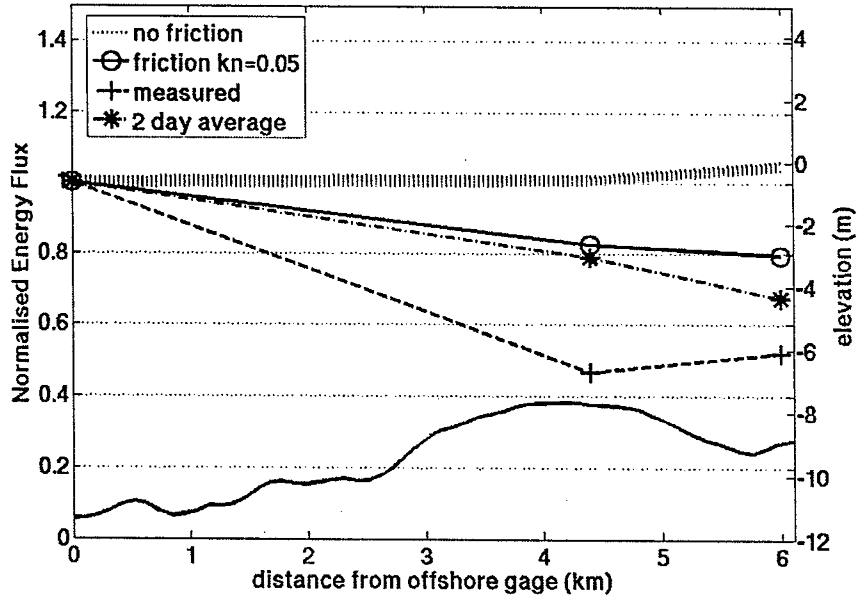

Figure 7. Energy flux for low-frequency (0-0.15 Hz) band at 08:00 GMT on 15 November, 2001, based on measurements and SWAN model predictions. Dashed line on top shows SWAN model result for no-friction case. Open circles denote results using Madsen et al. (1988) friction model within SWAN with standard coefficient of 0.05 for bottom roughness height. Asterisks denote mean for two-day period ($N = 33$). Solid line at bottom shows bathymetry.

Figure 8 provides similar results for the mid-frequency (0.15-0.25 Hz) band. In this case the Madsen friction model (Madsen et al. 1988) with the standard coefficient of 0.05 for roughness height reproduces the dissipation between the offshore instrument and the shoal, but underpredicts dissipation in the lee. Taken together, Figures 7 and 8 suggest that the either the frequency or depth dependence of the energy dissipation term within the model does not match the measurements.

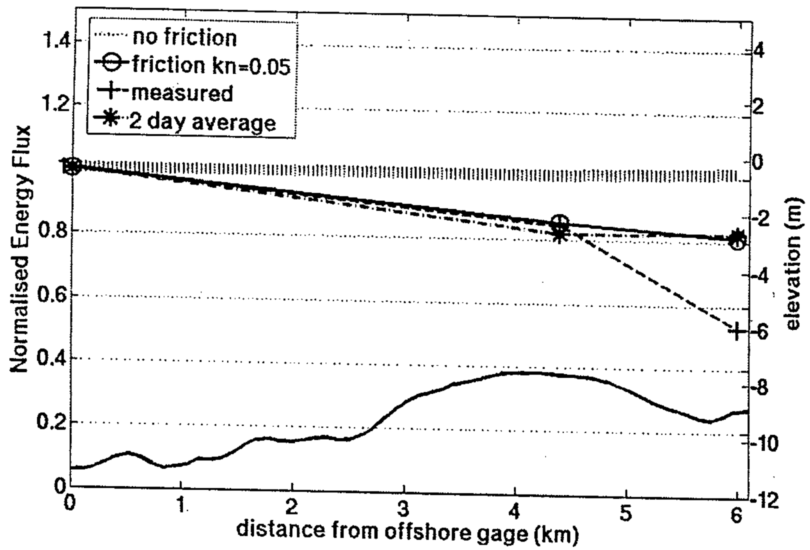

Figure 8. Energy flux for mid-frequency (0.15-0.25 Hz) band at 08:00 GMT on 15 November, 2001. Dotted line shows SWAN result in absence of bottom friction. Open circles denote results using Madsen friction model within SWAN with standard coefficient of 0.05 for bottom roughness height. Asterisks denote mean for two-day period ($N = 33$). Solid line at bottom shows bathymetry.

SWAN includes three options for energy dissipation within the bottom boundary layer, all of them assuming the following form:

$$S_b(\sigma,\theta) = -C_{bottom} \frac{\sigma^2}{g^2 \sinh^2 kh} E(\sigma,\theta) \qquad (2)$$

Here $S_b(\sigma,\theta)$ is an energy sink term, proportional to the local energy density $E(\sigma,\theta)$. C_{bottom} varies depending on the chosen model, but does not include any frequency dependence, except for the binary dependency of the Hasselmann and Collins (1968) model, which has separate coefficients for sea and swell. For the nominal 10 m depths encountered at the site considered here, the frequency dependence of this energy dissipation term is as shown in Figure 9.

As shown in Figure 9, the model predicts little energy dissipation for the mid-frequency band for the depths encountered at the Long Bay site, compared to the low frequency band, whereas the measurements show measurable (and similar) dissipation for both bands.

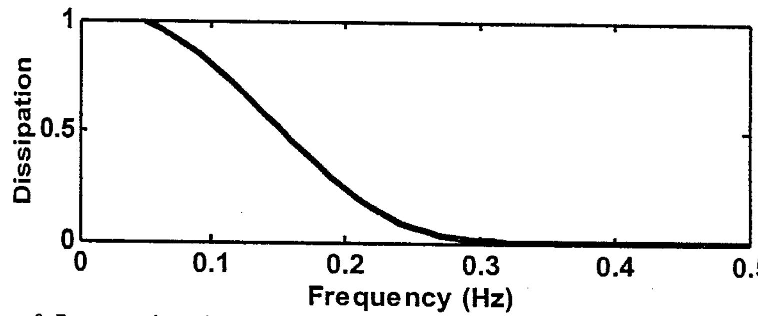

Figure 9. Frequency dependence of wave energy dissipation term in SWAN model for water depth of 10 m. Ordinate shows percentage of energy dissipated at any given frequency compared to percentage dissipated for $f = 0.05$ Hz.

To this point, spatial and temporal variations in bottom friction have not been addressed. Diver inspections at the site on numerous occasions reveal, not surprisingly, that bedforms are often, but not always present over sand-covered portions of the area, and bedforms are sometimes present in one part of the domain but not another. This, and the fact that substantial portions of the domain contain exposed rock, suggests high variability in bottom roughness, although the available data do not allow more than speculation regarding magnitudes of bottom roughness heights. Newly acquired data at the site include sonar altimetry that will reveal the time-dependency in bedforms at the site. Future work will also include investigation of the directional characteristics of the wave energy dissipation problem.

6. Conclusions

Three months of measurements of directional wave energy spectra along a shore-normal transect were analyzed to investigate the significance of bottom friction and other energy sink terms for waves propagating across a large shoal. The shoal is shore oblique, 2 km x 10 km in extent, and rises up to 3 m above ambient bathymetry at 10 m depth. It is composed primarily of sand-sized sediments, and sits on what is an otherwise sediment starved portion of the continental shelf near Myrtle Beach, South Carolina.

Measurements were made with upward-looking acoustic Doppler sensors that recorded directional wave energy spectra every 1.5 hours at three locations. Instruments were deployed offshore of the shoal as well as directly on its crest and in its lee, at depths of 7-12 m. The three-month measurement period featured two days when waves were relatively energetic (zero-moment wave heights exceeding 1 m) while winds were light (mean wind speeds < 5 m/s). This subset of the dataset was investigated to quantify wave energy dissipation and the ability of an existing wave transformation model to describe the dissipation.

Whitecapping, wave breaking, mean flows, and wind inputs were all ruled out as contributing factors to the observed dissipation during the selected two-day period, as well as any interactions with the seafloor other than dissipation due to the presence of the bottom boundary layer. Waves typically lost 20-30% of their incident energy flux while propagating the 6 km between the offshore and inshore measurement stations.

Observed dissipation showed a preference for low frequencies, as predicted by most models of bottom friction effects (e.g. Hasselmann and Collins 1968, Collins 1972, Madsen et al. 1988). But the frequency dependence of the observed dissipation differed between the measurements and models, with the measurements showing more dissipation in the mid-frequency band than predicted by the models. These differences could be due to inadequacies in the description of energy losses due to bottom friction, or could be a result of wave-wave interactions that are not adequately described in the wave transformation model. The model did, however, yield a good description of the time-averaged dissipation, even without calibration.

Temporal and spatial variations in bottom roughness height are both thought to be significant at the site considered. Temporal variations will be evident in newly acquired data that include sonar altimetry. Spatial variations result from the fact that the region is sediment starved and features many rock outcrops. It may be possible to improve model results by representing rock and sand regions by different roughness coefficients.

Acknowledgments

Funding for the work described in this paper was provided by the U.S. Geological Survey and the South Carolina Sea Grant Consortium.

References

Ardhuin, F., O'Reilly, W.C., Herbers, T.H.C., and Jessen, P.F., 2004. Swell transformation across the continental shelf. Part I: attenuation and directional broadening. *J. Phys. Oceanography*, 33, 1921-1939.

Bretschneider, C.L., and Reid, R.O., 1954. Changes in wave height due to bottom friction, percolation, and refraction. Tech. Memo., U.S. Army Beach Erosion Board, No. 45, 36 pp.

Baldwin, W.E., Morton, R.A., Denny, J.F., Dadisman, S.V., Schwab, W.C., Gayes, P.T., and Driscoll, N.W., 2004, Stratigraphic framework maps of South Carolina's Long Bay from Little River Inlet to Winyah Bay: U.S. Geological Survey Open-File Report 04-1013, 30 p.

Booij, N., Ris, R.C., and Holthuijsen, L.H., 1999. A third-generation wave model for coastal regions. 1. Model description and validation. *J. Geophys. Res.*, 104(C4), 7649-7666.

Collins, J.I., 1972. Prediction of shallow-water spectra. *J. Geophys. Res.*, 77(15), 2693-2707.

Dean, R.G., and Dalrymple, R.A., 1991. Water Wave Mechanics for Engineers and Scientists, World Scientific, Singapore.

Hasselmann, K., and Collins, J.I., 1968. Spectral dissipation of finite-depth gravity waves due to turbulent bottom friction. *J. Marine Res.*, 26(1), 1-12.

Herbers, T.H.C., Hendrickson, E.J., and O'Reilly, W.C., 2000. Propagation of swell across a wide continental shelf. *J. Geophys. Res.*, 105(C8), 19,729-19,737.

Madsen, O.S., Poon, Y.-K., and Graber, H.C., 1988. Spectral wave attenuation by bottom friction: theory. *Proc. Intl. Conf. on Coastal Engineering*, ASCE, 492-504.

Ojeda, G. Y., Gayes, P.T., Van Dolah, R.F. and Schwab, W.C., 2004. Spatially quantitative seafloor habitat mapping: example from the Northern South Carolina inner continental shelf. *Estuarine, Coastal and Shelf Science*, 59, 399-416.

Putnam, J.A., and Johnson, J.W., 1949. The dissipation of wave energy by bottom friction. *EOS Tran. AGU*, 30, 67-74.

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
06-06-2005	Conference Proceedings (not referred)	

4. TITLE AND SUBTITLE Mesoscale Wave Energy Dissipation over Heterogeneous Sediments	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 62435N
6. AUTHOR(S) Work, Paul, Demir, Huseyin, Kaihatu, James A., Voulgaris George	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 73-M125-04-5
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory Oceanography Division Stennis Space Center, MS 39529-5004	8. PERFORMING ORGANIZATION REPORT NUMBER NRL/PP/7320--04-5029
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research 800 N. Quincy St. Arlington, VA 22217-5660	10. SPONSOR/MONITOR'S ACRONYM(S) ONR
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Measurements describing the evolution of wave energy spectra as waves propagate across a large shoal are described. The shoal is shore oblique, 2 km by 10 km in extent, with relief of up to three meters over bathymetry with ambient depth 10-12 m. The region is sediment starved, and bottom roughness displays spatial variability due to rock outcrops. Field measurements intended to investigate the effects of this shoal on waves, currents, and sediment transport in its lee reveal strong cross-shore gradients in energy density and energy flux, well outside of the surf zone, in conditions of minimal wind, which are attributed to bottom friction. The dissipation displays the expected frequency dependence, in that it decreases in significance as wave frequency increases, but this trend is not as strong as available theoretical predictions would suggest.

15. SUBJECT TERMS

wind wave energy losses; bottom friction; surface gravity waves; bathymetry; ambient; spatial variability; cross-shore gradients; mesoscale wave; heterogeneous sediments

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					James A. Kaihatu
Unclassified	Unclassified	Unclassified	UL	7	19b. TELEPHONE NUMBER *(Include area code)* 228-688-5710

PUBLICATION OR PRESENTATION RELEASE REQUEST

Pubkey: 4254 NRLINST 5600.2

1. REFERENCES AND ENCLOSURES	2. TYPE OF PUBLICATION OR PRESENTATION		3. ADMINISTRATIVE INFORMATION
Ref: (a) NRL Instruction 5600.2 (b) NRL Instruction 5510.40D Encl: (1) Two copies of subject paper (or abstract)	( ) Abstract only, published ( ) Book ( ) Conference Proceedings (refereed) ( ) Invited speaker ( ) Journal article (refereed) ( ) Oral Presentation, published ( ) Other, explain	( ) Abstract only, not published ( ) Book chapter (X) Conference Proceedings (not refereed) ( ) Multimedia report ( ) Journal article (not refereed) ( ) Oral Presentation, not published	STRN NRL/PP/7320-04-5029 Route Sheet No. 7320/ Job Order No. 73-M125-04-5 Classification X U ___ C Sponsor ONR approval obtained X yes ___ no

4. AUTHOR

Title of Paper or Presentation

Mesoscale Wave Energy Dissipation over Heterogeneous Sediments

Author(s) Name(s) (*First,MI,Last*), *Code, Affiliation if not NRL*

Paul Work, Huseyin Demir, James M Kaihatu, George Voulgaris

It is intended to offer this paper to the **Proceedings of 29th Int. Conference on Coastal Engineering**
(*Name of Conference*)

19-SEP - 24-SEP-2004, Lisbon, Portugal, Unclassified
(*Date, Place and Classification of Conference*)

and/or for publication in **Proceedings of 29th Int. Conference on Coastal Engi**
(*Name and Classification of Publication*) (*Name of Publisher*)

After presentation or publication, pertinent publication/presentation data will be entered in the publications data base, in accordance with reference (a).
It is the opinion of the author that the subject paper (is ____) (is not X) classified, in accordance with reference (b).
This paper does not violate any disclosure of trade secrets or suggestions of outside individuals or concerns which have been communicated to the Laboratory in confidence. This paper (does ____) (does not X) contain any militarily critical technology.
This subject paper (has ____) (has never X) been incorporated in an official NRL Report.

James M Kaihatu, 7322
Name and Code (*Principal Author*) (Signature)

5. ROUTING/APPROVAL

CODE	SIGNATURE	DATE	COMMENTS
Author(s) Kaihatu		11/10/04	Need by 13 Dec. This is proceedings after the conference. Publicly accessible sources used for this publication
Section Head Allard	(acting)	11/10/04	
Branch Head Gregg A. Jacobs, 7320		11/12/04	
Division Head Ruth H. Preller, 7300		11/16/04	1. Release of this paper is approved. 2. To the best knowledge of this Division, the subject matter of this paper (has ____) (has never X) been classified.
Security, Code 7030.1		11/22/04	1. Paper or abstract was released. 2. ~~A copy is filed in this office~~ 550-430-4
Office of Counsel, Code 1008.3		11/18/04	
ADOR/Director NCST E.O. Hartwig, 7000			
Public Affairs (*Unclassified/ Unlimited Only*), Code 7030.4		11/22/04	
Division, Code			
Author, Code			

HQ-NRL 5511/6 (Rev. 12-98) (e) THIS FORM CANCELS AND SUPERSEDES ALL PREVIOUS VERSIONS

6. DISTRIBUTION STATEMENTS (Author to check appropriate statement and fill in reasons as required)

☑ A - Approved for public release, distribution is unlimited.

☐ B - Distribution authorized to U.S. Government agencies only *(check reason below):*

- ☐ Foreign Government Information
- ☐ Contractor Performance Evaluation
- ☐ Critical Technology
- ☐ Proprietary Information
- ☐ Administrative/Operational Use
- ☐ Premature Dissemination
- ☐ Test and Evaluation
- ☐ Software Documentation
- ☐ Cite "Specific Authority ______________________"
  (Identification of valid documented authority)

Date statement applied ______________

Other requests for this document shall be referred to ______________________
(Insert Controlling DOD Office)*

☐ C - Distribution authorized to U.S. Government agencies and their contractors *(check reason below):*

- ☐ Foreign Government Information
- ☐ Software Documentation
- ☐ Administrative/Operational Use
- ☐ Critical Technology
- ☐ Cite "Specific Authority ______________________"
  (Identification of valid documented authority)

Date statement applied ______________

Other requests for this document shall be referred to ______________________
(Insert Controlling DOD Office)*

☐ D - Distribution authorized to DOD and DOD contractors only *(check reason below):*

- ☐ Foreign Government Information
- ☐ Critical Technology
- ☐ Software Documentation
- ☐ Cite "Specific Authority ______________________"
  (Identification of valid documented authority)
- ☐ Administrative/Operational Use

Date statement applied ______________

Other requests for this document shall be referred to ______________________
(Insert Controlling DOD Office)*

☐ E - Distribution authorized to DOD components only *(check reason below):*

- ☐ Proprietary Information
- ☐ Premature Dissemination
- ☐ Critical Technology
- ☐ Foreign Government Information
- ☐ Software Documentation
- ☐ Direct Military Support
- ☐ Administrative/Operational Use
- ☐ Contractor Performance Evaluation
- ☐ Test and Evaluation
- ☐ Cite "Specific Authority ______________________"
  (Identification of valid documented authority)

Date statement applied ______________

Other requests for this document shall be referred to ______________________
(Insert Controlling DOD Office)*

☐ F - Further dissemination only as directed by ______________________
(Insert Controlling DOD Office)*

Date statement applied ______________ or higher DOD authority ______________________

☐ G - Distribution authorized to U.S. Government agencies and private individuals or enterprises eligible to obtain export-controlled technical data in accordance with regulations implementing 10 U.S.C. 140c.

Date statement applied ______________

Other requests for this document shall be referred to ______________________
(Insert Controlling DOD Office)*

*For NRL publications, this is usually the Commanding Officer, Naval Research Laboratory, Washington, DC 20375-5320

7. OTHER LIMITATION

☐ Classification ☐ NOFORN ☐ DTIC exempt (explain) ______________________

____
Classification Review
(Initial/Date)

Substantive changes made in this document after approval by Classification Review and Public Release invalidate these reviews. Therefore, if any substantive changes are made by the author, Technical Information, or anyone else, the document must be returned for another Classification Review and Publication Release.

8. INSTRUCTIONS

Author completes and submits this form with the manuscript via line channels to the division head for review and approval according to the routing in Section 4.

1. NRL Reports...Submit the diskette (if available), manuscript, typed double-spaced, complete with tables, illustrations, references, draft SF 298, and proposed distribution list.
2. NRL Memorandum Reports...Submit a copy of the original, typed manuscript complete with tables, illustrations, references, draft SF 298, and proposed distribution list.
3. NRL Publications or other books, brochures, pamphlets, proceedings, or any other printed publications..........................Handled on a per case basis by Site Technical Information Office.